Scientific Reports

https://doi.org/10.1038/s41598-026-46795-1

Article in Press

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Received: 6 December 2024

Accepted: 27 March 2026

Published online: 01 April 2026

Cite this article as: Rodríguez-López E.S., Ojedo-Martín C., Del-Fresno-González J. *et al.* Pelvic floor morphofunctional characteristics in female rugby players beyond the tackle. Pelvic floor muscles in high-impact sports. *Sci Rep* (2026). https://doi.org/10.1038/s41598-026-46795-1

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Pelvic Floor Morphofunctional Characteristics in Female Rugby Players Beyond the Tackle

Pelvic floor muscles in high-impact sports

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Abstract

Rugby is a high-impact sport that may impose substantial mechanical demands on the pelvic floor muscles (PFMs) and has been associated with stress urinary incontinence (SUI). This cross-sectional study assessed pelvic floor morphofunctional characteristics in 27 nulliparous female rugby players using digital palpation, 2D transperineal ultrasound, and surface electromyography (sEMG) in supine and standing positions, both at rest and during tonic contractions. Ten players presented an anteroposterior diameter of the levator hiatus (LH (ap)) > 4.5 cm in supine, which was significantly larger in standing ($p < 0.001$), especially in those with SUI ($p = 0.010$). Variations in electrical activity were associated with levator hiatus dimensions, suggesting possible functional adaptations. Incontinent players showed higher activation percentages ($p = 0.029$), while continent players showed greater amplitude during MVC. A larger LH (ap) under load was observed particularly in players with SUI, who also showed a pattern of greater myoelectric excitation, potentially reflecting increased muscular demand during effort. Pelvic floor function in athletes exposed to repeated high-impact loading may depend on the balance between structural support and muscular activity, upporting the relevance of targeted evaluation and preventive strategies. Given the cross-sectional design, these results should be interpreted as associative.

Key Points

- The anteroposterior diameter of the levator hiatus appears to be a sensitive marker of load-related pelvic floor differences, as it was larger in standing than in supine.
- Several nulliparous rugby players showed levator hiatus dimensions comparable to ranges previously described in pregnancy or postpartum populations, although such comparisons are descriptive only.
- The levator plate angle varied mainly with voluntary contraction and pelvic floor muscle strength, suggesting that it may reflect contractile function more closely than structural pelvic floor differences.
- Players with stress urinary incontinence showed greater hiatus distensibility in standing and a pattern of higher pelvic floor muscle activation, suggesting greater muscular demand during effort.

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Keywords: pelvic floor; electromyography; ultrasonography; sportswomen; rugby

1. Introduction

Female participation in sport has grown notably, both at the recreational and competitive levels. This increase has been associated with a range of health issues among female athletes [1], including a higher prevalence of irregular or absent menstrual cycles, eating disorders, musculoskeletal injuries, stress fractures and pelvic floor dysfunction (PFD) in physically active women [2,3]. Stress urinary incontinence (SUI) is the most prevalent PFD [4,5], defined as the involuntary loss of urine during physical exertion [4] . While traditionally linked to factors such as parity, age, or obesity [6–8], SUI is increasingly reported among young, nulliparous,

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and physically active women with normal body mass index (BMI) [9,10]. Female athletes are 2-3 times more at risk for SUI compared to other populations and 5.45 times more at risk than male athletes [11]. A meta-analysis of athletes aged 18 to 45 years, without recent parity, showed a prevalence of SUI of 20.7% [12]. A study analyzing the prevalence of SUI in adultwomen found that the point prevalence of SUI among female competitive athletes, female recreational athletes, and sedentary women was 21%, 8%, and 11%, respectively [13]. A recent meta-analysis reported 36% prevalence of urinary incontinence (UI) among female athletes across both high- and low-impact sports [8]. Additionally, a 2020 meta-analysis reported SUI rates of 36.4%, 50%, and 64% in female nulliparous athletes participating in low-, moderate-, and high-impact sports, respectively [14].

In recent decades, participation in sports, particularly at high-performance levels, has been increasingly recognized as a contributing risk factor for the development of SUI [15–17]. The main cause is thought to be a rise in intra-abdominal pressure (IAP) followed by abdominal muscle contraction in the absence of prior pelvic muscle contraction [18]. However, other contributing factors such as low energy availability and Relative Energy Deficiency in Sport (REDs) have also been implicated in the development of SUI in female athletes [19]. The level of impact associated with the type of sport negatively influences the occurrence and severity of SUI, with track and field, volleyball and rugby being considered high-impact activities [18,20,21].

Furthermore, this condition could affect their performance, with 29% of women reporting a decrease in performance due to UI in an online questionnaire [22]. Given that women's rugby is currently the fastest growing sport worldwide [23], and it is projected that by 2026 there will be 6 million female rugby players globally, it is crucial to understand how high impact activity influences their PFMs [24]. Rugby is regarded as a high-impact sport due to its physically demanding activities, such as running and tackling. The increased risk of UI in this context may be attributed to insufficient pre-impact PFMs contraction [25], or to muscle fatigue resulting from repeated tackles [7,26].

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Although pelvic floor morphology has been studied in athletes [27,28], the relationship between structural changes and functional performance remains unclear, particularly in high impact, contact sports. While PFMs activation appears position-dependent [29] the morphological response of the levator hiatus (LH) and urogenital hiatus (UGH) to postural changes has not been adequately explored in nulliparous athletic populations. Current literature primarily addresses peripartum cohorts [30], leaving a gap in understanding how repetitive mechanical load, such as that experienced in rugby, affects pelvic floor integrity. This study integrates morphological (2D ultrasound) and functional (digital palpation and sEMG) assessments to investigate pelvic floor morphofunctional characteristics in nulliparous female rugby players. Therefore, we hypothesized that players would show a larger LH, potentially consistent with adaptation to repeated high-impact loading. We also expected that players with PFD would show greater hiatus distensibility and altered PFMs activation, especially in standing.

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2. Materials and Methods

This cross-sectional study was carried out in a single session during which surface electromyography (sEMG) measurements, digital palpation and ultrasound were used to assess PFMs. The study design adhered to the ethical principles delineated in the Declaration of Helsinki [31]. The research data were anonymized and treated confidentially in accordance with new European data protection regulations [32] and the Spanish LOPD norms [33]. This study was evaluated and approved by the Ethics Committee of University Camilo José Cela (code 18_FRIU, 22 January 2022; Madrid, Spain). The research was carried out and described according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [34].

2.1. Participants

Female rugby players over 18 years of age were recruited from local teams. To ensure consistent and prolonged exposure to high-impact forces on the pelvic floor,

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participants were required to meet specific inclusion criteria: a minimum of 2 hours of training per day, at least three days per week (≥3 sessions/week), with no fewer than 5 years of rugby experience. Additionally, only nulliparous women aged between 18 and 35 years were included. Each was recruited through advertisements and pre-workout information sessions. In addition, participants were provided with detailed information about the study, the potential risks and benefits, and their informed consent, both verbal and written, was obtained before the start of the study. All assessments were conducted between February 2024 and June 2024.

The exclusion criteria were pregnant women, those with urgent UI, pelvic organ prolapse - defined either by objective clinical findings, by self-reported symptoms or by imaging techniques such a TPUS-, active or recurrent genitourinary tract infections, those experiencing specific phobias related to medical procedures (e.g., fear of internal examinations), or those unable to tolerate the insertion of an intravaginal probe due to increased vaginal tone [35]. Participants were also excluded if they had neuromuscular diseases, allergies to heavy metals, an injury or leg length discrepancy greater than 0.7 cm [36], or a self-reported history of diabetes mellitus, urogynecological or pelvic surgery, pelvic irradiation, hypermobility syndrome or mobility impairments that could affect PFMs morphology, stiffness or contractility. All participants attended a single data collection session.

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2.2. Measurement procedures and data collection

All measurements were conducted by the same certified pelvic health physiotherapist with more than 10 years of clinical experience in women’s health. All the assessments explained below were carried out consecutively.

2.2.1. Questionnaire

An online questionnaire was completed by the participants through the Survey Monkey® platform (San Mateo, CA, USA). In this questionnaire, anthropometric information (age, height and weight), medical history and sports practice routine were collected. BMI was calculated as weight divided by height squared (kg/m^2) and

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classified according to WHO criteria. The evaluation of UI was performed through the International Consultation on Incontinence Questionnaire-Short Form (ICIQ-SF) [37,38]. Two groups of women were formed: players who frequently experienced SUI (one or more episodes per week) and those who did not.

2.2.2. PFMs assessment by vaginal palpation: Modified Oxford Grading Scale (MOS)

The evaluation of PFMs was conducted in a single session, preceding any physical activity. Several methods are used to assess and measure the activity and strength of the PFMs in clinical practice and research, such as manual palpation, transperineal ultrasound (TPUS), dynamometry and sEMG, but none of them is considered a "gold standard" for an objective assessment of the pelvic floor [39].

To evaluate the voluntary contraction of the PFMs, it is necessary to perform an intracavitary assessment through manual palpation. Participants were instructed to void their bladders prior to undergoing measurements. Participants assumed a modified lithotomy position, with a pillow under their heads, hips slightly abducted and flexed approximately 30 degrees, knees flexed approximately 30 degrees, and feet resting on the examination table.

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First, the participants were instructed on how to perform a correct pelvic floor contraction and subsequently, hypoallergenic water-based lubricating gel (Sulky®, Kennesaw, GA, USA) was applied to the examiner’s gloved fingers to facilitate the digital evaluation and ensure participant comfort. Although participants had not received prior structured pelvic floor training, all were guided by a physiotherapist during the assessment to ensure proper contraction technique, using digital palpation and real-time TPUS as biofeedback tools. When the contraction was correct, the specialized physiotherapist evaluated the contractile capacity of the PFMs using the MOS. The score ranged from 0 to 5 (from a minimum score of grade 0, or none, to grade 5, or strong) [40,41].

2.2.3. 2D transperineal ultrasound

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TPUS or translabial 2D ultrasound involves placing a convex probe externally between the labia majora of the female perineum to directly visualize and monitor the pelvic viscera and PFMs in real-time [42]. This non-invasive method offers various measurement systems for quantifying and analyzing levator ani (LA) activity, including bladder neck displacement, anteroposterior diameter of the levator hiatus (LH (ap)), and the levator plate angle (LPA) measurement. The technique is widely documented in scientific literature as being less invasive compared to previous methods [43–45].

The values were obtained using an HM70 ultrasound machine (Samsung® HS50, Suwon, South Korea) with a convex CA1-7AD probe. For each participant, the transducer was covered with a probe cover, and a conductive gel (Transonic®, Diagnostic Imaging Gel, USA) was applied both inside and outside the cover to optimize acoustic coupling and image quality while ensuring participant comfort. The transducer was positioned between the labia majora to correctly visualize the inferior and posterior border of the pubic symphysis, the LA plate, the bladder, and the bladder neck. Once the structures were identified in each subject, the parameters of depth, frequency, focus position, and gain were adjusted to optimize the image. Before taking measurements, participants who exhibited poor motor control during manual palpation underwent reeducation with visual feedback via the ultrasound image.

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TPUS measurements were taken both at rest and during MVC in the supine position and standing position, as shown in Figure 1, with a semi-full bladder. In the supine position, the athletes were placed in the same position as described previously for manual assessment. In the standing position, covered with their own towel, the ultrasound was performed after positioning them with a neutral pelvis, unlocked knees, and sufficient separation of the lower limbs to position the probe without affecting the patient’s stance.

The LH (ap) and the LPA were recorded according to the methodology of Hans P. Dietz [46], as shown in Figure 1. The LH (ap) is obtained by measuring the distance in cm between the inferior and posterior border of the pubis and the most anterior part of the LA plate. The LPA is obtained from the angle formed by the most anterior face of the LA plate with a horizontal line parallel to the transducer, drawn from the inferior and posterior border of the pubis. For each measurement, two recordings were taken at the end of exhalation, and the mean value was calculated.

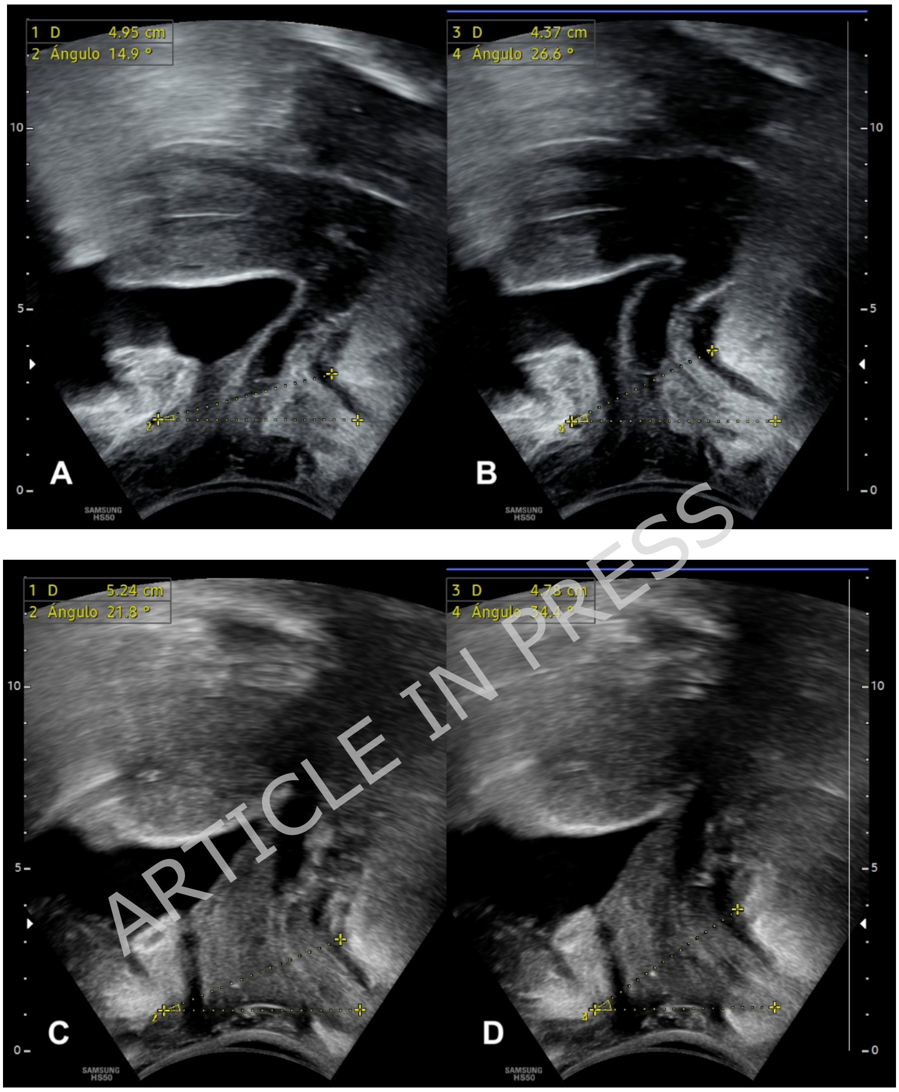

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Figure 1. TPUS in the midsagittal plane. (A) Supine position at rest; (B) Supine position during MVC; (C) Standing position at rest; (D) Standing position during MVC.

Previous literature has reported LH (ap) values of approximately 4.5 cm in nulliparous women and up to 5.0 cm in pregnant or postpartum populations, particularly in the third trimester or early postpartum period [47]. These values were

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considered as reference ranges to contextualize the morphological adaptations observed in our sample.

2.2.4. Surface Electromyography

The PFMs activity was measured using sEMG mDurance® (Granada, Spain), a scientifically validated tool in the field of physiotherapy and sports sciences [48,49] that combines three parts: a portable sEMG, an operating system, and cloud analysis. The sampling frequency was 2 kHz with an amplification gain of 1000. sEMG and movement signals were wirelessly transmitted via Bluetooth, following validated synchronization procedures for biomechanical signal acquisition [50,51].

At the beginning of sEMG measurement, all the participants were instructed by an expert physiotherapist to ensure consistent contraction patterns, following validated pelvic floor EMG acquisition protocols [50],[52,53]. Then a verbal instruction for the voluntary contraction of the PFMs was given to them [50]. Pre-recorded audio cues were used to indicate the timing of contraction, rest, and repetition, ensuring standardized verbal instructions and consistent stimulus across all participants [54]. A Periform® single-use bipolar vaginal probe (Neen HealthCare, Dereham, United Kingdom) with two electrodes, two independent tracks, one channel, and a total weight of 16 g was employed for this purpose. Antiallergic gel was used by a specialist physiotherapist to introduce it. The vaginal probe was inserted vaginally with the electrodes placed in the 3 and 9 o'clock positions. A reference electrode was placed on the anterior superior iliac spine in accordance with SENIAM recommendations [55].

The adapted Glazer Protocol [56] was used to collect the electrical activity of the PFMs. First, the patient rests 10 min in supine position, after which the following measurements were taken: (i) *Maximal voluntary contractions* (MVC) - two 5-second maximal contractions of the PFMs [50,57], each followed by 30 seconds of rest [58]. (ii) *Baseline* - 60 seconds of resting EMG activity, we measured the average muscle activity at rest. (iii) *Tonic contractions*- five 10-second sustained contractions with 10-second relaxations in between. Measurements of baseline and tonic contractions were then repeated in standing position.

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The “peak amplitude” refers to the maximum value obtained during contraction. “Average amplitude” values were also extracted to represent sustained muscle activity. The reference value set as 100% for sEMG normalization was the MVC. Then, the average of the two mean MVC was calculated and used in the data normalization (ratio of the absolute values of the amplitude of the sEMG signal expressed as a percentage of common reference value). The values were represented in microvolts (μV) and ratio (%) according to the data normalization in supine position.

2.3. Statistical Analysis

The Gpower software (Kiel University, Kiel, Germany) was used to calculate the sample size. Then, repeated measures with an effect size of 0.80, an α error probability of 0.05, and statistical power of 0.90 were employed for the sample size calculation. Considering the possibility of a sample loss of 15%, the estimated number of subjects was 30 female rugby players, based on the specified parameters.

Data were analyzed using the IBM Statistics Package for Social Science, v.26 (IBM Corp, New York, NY, USA). Data were provided as the mean and standard deviation, along with 95% confidence intervals (95%CI). When appropriate, data were provided as percentages. Before performing the analysis, Shapiro–Wilk tests were used to check the normality of the variables ($p > 0.05$). Repeated measures ANOVA was used to analyze within-subject differences in LH dimensions and PFMs activation (TPUS and sEMG values) between supine and standing positions. It was also applied to assess between-group differences (continent vs. incontinent players, and players with enlarged vs. non-enlarged hiatus). When significant main effects were detected, Bonferroni-adjusted post-hoc tests were conducted to identify specific groups or positional differences. Bivariate correlations among quantitative variables were assessed through Pearson’s coefficient. The level of confidence was set at 95% and significance was set at $p < 0.05$.

3. Results

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Out of the thirty-two nulliparous female rugby players initially recruited, five were excluded from the analysis. Three participants were unable to have the intracavitary probe inserted due to vaginismus, while one woman had an active infection of the genitourinary tract. Additionally, another player was excluded because they sustained a lower limb injury that prevented them from maintaining a stable standing position. The final sample consisted of twenty-seven nulliparous women with a mean age of 25.14 (3.39) years and a BMI of 24.1 (2.53) kg/m^2. They were naturally cycling with regular menstrual periods. Eight participants were classified as overweight. Six individuals reported constipation, none had a history of gynecological surgery, and the group had an average rating of 3.76 out of five on the MOS. Only one woman identified as Black. 44.4% of female players experienced SUI with an ICIQ-SF score of 5.81 (3.91). Nine of the players suffered from slight incontinence (<10.5 points), one of them had moderate UI and another severe UI (>13.5 points). All were female rugby players with a homogeneous training regimen, engaging in approximately three hours of activity per day and training at least three days per week (≥3 sessions/week), with a minimum of 5 years of rugby experience. The sample included 19 amateur and 8 elite-level athletes competing in organized leagues. Approximately half of the players reported knowing exercises to strengthen their pelvic floor, however, nearly 90% indicated, via questionnaire responses, that they did not incorporate these exercises into their training regimens or daily routines.

3.1 Results of the morphology of the PFMs.

Ten sportswomen (37%) had the LH (ap) greater than 4.5 cm at rest in the supine position. When the measurements were performed standing, twenty women (74.07%) exceeded 4.5 cm, and almost 30% (n=8) exceeded 5 cm in diameter at rest. When comparing the TPUS measurements (Table 1), repeated measures ANOVA revealed a significant main effect of condition (F (3,26) = 51.9, $p < 0.001$, $\eta^2 = 0.666$), indicating that LH (ap) dimensions varied across positions and contraction states. Pairwise comparisons showed that LH (ap) was significantly larger in

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standing than in supine, both at rest (+0.27 cm, +7%, $p < 0.001$) and during MVC (+0.36 cm, +9% $p < 0.001$). Conversely, MVC reduced LH (ap) compared to rest in both supine (-0.51 cm, $p < 0.001$) and standing (-0.42 cm, $p < 0.001$) (Figure 2). No significant difference was found between supine rest and standing MVC ($p = 0.091$). 37% of players in supine and 66.6% (n=18) when standing continued with a diameter greater than 4 cm when contracting the pelvic floor.

Repeated measures ANOVA revealed a significant main effect of condition on LPA (F (3,26) = 24.7, $p < 0.001$, $\eta^2 = 0.518$), indicating that the LPA varied across positions and contraction states. Pairwise comparisons showed that MVC significantly increased LPA compared to rest, both in supine (+14.8°, $p < 0.001$) and standing (+15.4°, $p < 0.001$). In addition, MVC in standing produced a larger LPA than in supine (+12.2°, $p < 0.001$). No significant differences were observed between resting positions ($p = 0.189$). The interaction with MOS was significant (F (9,69) = 2.86, $p = 0.006$, $\eta^2 = 0.272$), suggesting that pelvic floor strength influenced LPA behavior, although between-group comparisons did not reach significance ($p = 0.911$). There were no significant differences in TPUS measurements according to the weight status, nor constipation.

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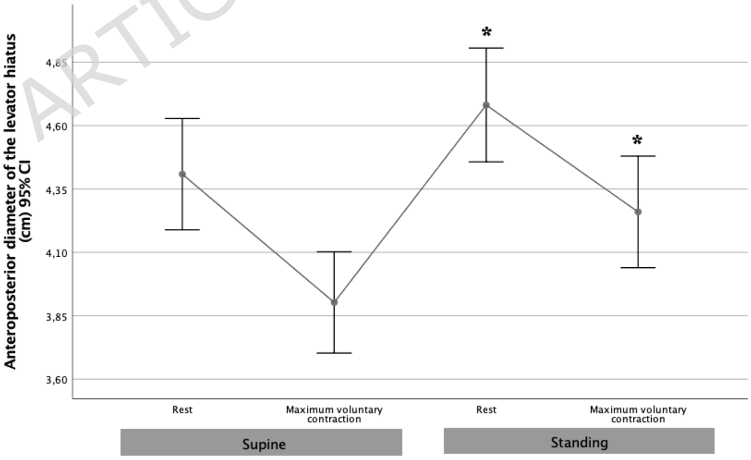

Figure 2. LH (ap) in supine and standing. (*) $p < 0.05$, significant differences in LH (ap) at rest and during MVC between supine and standing positions.

Twelve female rugby players experienced SUI (44.4%). There were no significant differences according to age, weight status, constipation, LH (ap) or LPA between continent athletes and incontinent athletes ($p > 0.05$). Although no significant between-group main effects were found, post-hoc tests were performed to explore within-group positional differences. In incontinent players, the LH (ap) increased significantly from supine to standing rest (+0.33 cm, $p = 0.010$), whereas this change was not significant in continent players (p = 0.085) (Table 2). Activation of the PFMs significantly reduced the LH (ap) in both positions ($p < 0.001$), with no significant differences observed in LPA.

3.2 Results of the electrical activity of the PFMs.

According to the activation of the PFMs, repeated measures ANOVA revealed a significant main effect of condition (F (4,26) = 77.3, $p < 0.001$, $\eta^2 = 0.771$), indicating that electrical activity varied significantly across testing conditions (Table 1). When comparing in relation to each position, significant differences were found in baseline of the PFMs ($p < 0.001$). In standing, the average and peak baseline amplitudes increased by approximately 10% and 20%, respectively. However, the mean amplitude of tonic contractions remained similar between positions (p = 1.000). Comparing between PFMs grades on the MOS, both amplitude of tonic contractions in supine and standing increased significant according increase PFMs grades ($p < 0.05$). There were no significant differences if there was weight status or constipation.

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Repeated measures ANOVA revealed a significant interaction between condition and LH size group (F (4,104) = 4.98, $p = 0.001$, $\eta^2 = 0.178$), indicating that PFM electrical activity varied according to hiatal dimensions. Players with a larger LH (ap) (> 4.4 cm) showed approximately 40% lower EMG amplitudes during tonic contractions in both supine and standing positions compared to those with a smaller hiatus. This difference was evident during tonic contractions in standing (+43 µV, $p < 0.01$) (Figure 3). However, baseline values are similar regardless of diameter size (Table 3).

This difference was especially marked during MVC in standing, where players with a narrower LH (≤ 4.4 cm) generated significantly higher EMG activity (+43 µV, $p < 0.01$). These findings suggest that a smaller LH (ap) may facilitate more efficient

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PFM recruitment under load (Figure 3). However, baseline values are similar regardless of diameter size (Table 3).

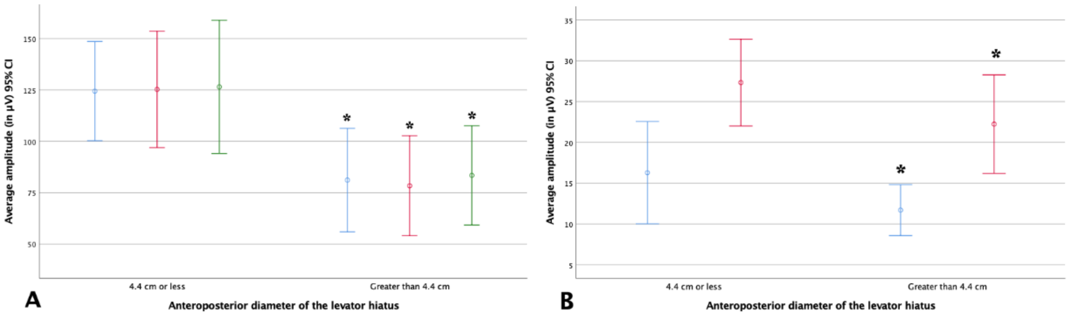

Figure 3. Pelvic floor activity according to LH (ap). (**A**) Blue represents MVC, red for tonic contractions in supine and green for tonic contractions in standing position. (**B**) Blue represents baseline in supine and red is baseline in standing position. (*) $p < 0.05$, significant differences in PFM electrical activity between players with LH (ap) ≤ 4.4 cm and those with LH (ap) > 4.4 cm.

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Repeated measures confirmed a strong main effect of condition on percentage of EMG activation (F (3,78) = 212.2, $p < 0.001$, $\eta^2 = 0.902$), indicating that pelvic floor activity varied consistently across basal activity and tonic contractions. Both continent and incontinent players increased their basal activation when standing compared to supine ($p < 0.05$), with a slightly greater rise observed in the incontinent group. Across conditions, incontinent players exhibited a higher relative percentage of basal and tonic activation than continent athletes ($p = 0.029$, $\eta^2 = 0.193$), suggesting greater effort was required to maintain similar functional output. Specifically, during the most demanding condition (tonic in standing), incontinent players showed ~25% higher relative activation than continent players ($p = 0.029$), despite the absence of significant differences in MVC amplitude between groups ($p > 0.05$). There were no significant differences according to weight status ($p > 0.05$),

In parallel, TPUS confirmed that MVC significantly reduced LH (ap) dimensions both in supine and standing ($p < 0.001$), reflecting effective hiatal closure under contraction. This reduction was proportionally similar in both groups, although the

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absolute LH (ap) was consistently larger in players with SUI. By contrast, LPA did not differ significantly between groups or conditions ($p > 0.05$), reinforcing the idea that LPA is less sensitive to dynamic changes than the hiatus.

Table 1**. Changes of different assessment methods of PFMs in supine and standing.**

	Supine		**Standing**		**Between positions**
	Mean±SD	**IC 95%**	**Mean±SD**	**IC 95%**	*p* Value (*)
TPUS measurements					
LH (ap) (cm)					
Rest	4.41±0.55	4.19-4.63	4.68±0.57	4.46-4.91	**<0.001**
MVC	3.90±0.50	3.70-4.10	4.26±0.56	4.04-4.48	**<0.001**
LPA (degree)					
Rest	29.56±9.54	25.79-33.34	26.38±8.20	23.13-29.62	0.494
MVC	42.38±9.16	38.75-46.00	41.29±10.52	37.13-45.45	1.000
Surface electromyography					
MVC					
Average amplitude (in µV)	103.65±44.82	85.15-122.15			
Peak amplitude (in µV)	169.07±72.12	139.3-198.84			
Baseline					
Average amplitude(in µV)	14.09±8.39	10.63-17.56	24.89±9.33	21.04-28.74	**<0.001**
Average amplitude (in %)	17.99±15.97	11.39-24.58	29.26±17.71	21.95-36.57	**<0.001**
Peak amplitude (in µV)	22.57±12.82	17.28-27.86	42.48±19.52	34.42-50.54	**<0.001**
Peak amplitude (in %)	17.82±17.56	10.57-25.07	30.15±19.67	22.03-38.27	**<0.001**
Tonic contractions					
Average amplitude(in µV)	102.76±48.47	82.75-122.77	105.83±50.85	84.84-126.82	1.000
Average amplitude (in %)	98.87±11.92	93.95-103.79	105.93±29.16	93.89-117.96	1.000

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	Supine		Standing		Between positions
	Mean±SD	**IC 95%**	**Mean±SD**	**IC 95%**	*p* Value (*)
Peak amplitude (in µV)	174.35±82.26	140.40-208.31	169.13±80.34	135.97-202.29	1.000
Peak amplitude (in %)	102.73±13.99	96.95-108.5	104.00±32.40	90.63-117.38	1.000

Abbreviations: *MVC*, maximum voluntary contraction; *SD*, standard deviation; *CI*, confidence interval. Significance a level was set at p < 0.05. Microvolt (µV) measurement unit. (*) Difference between positions according to the *p* value based on post-hoc of repeated measures ANOVA.

Table 2**. Muscle-activation values (average amplitude) in stress urinary incontinence**

		Supine			**Standing**			**Between positions**
		Mean	**SD**	**p Value (*)**	**Mean**	**SD**	**p Value (*)**	**p Value (*)**
TPUS measurements								
AP diameter (cm)								
Rest	No SUI	4.44	0.51	0.714	4.66	0.63	0.900	0.085
	SUI	4.36	0.62		4.69	0.50		**0.010**
MVC	No SUI	3.90	0.42	0.986	4.24	0.53	0.906	**<0.001**
	SUI	3.90	0.61		4.27	0.60		**<0.001**
Levator plate angle (degree)								
Rest	No SUI	27.98	9.18	0.346	25.84	9.12	0.714	1.000
	SUI	31.53	10.0		27.04	7.22		0.631
MVC	No SUI	42.47	8.96	0.951	42.70	11.74	0.444	1.000
	SUI	42.25	9.79		39.51	8.93		1.000
Surface electromyography (Average amplitude)								
MVC (in µV)	No SUI	113.60	37.36	0.152				
	SUI	92.87	51.15					
Baseline (in µV)	No SUI	13.32	6.40	0.643	25.19	9.40	0.872	0.019
	SUI	14.92	10.35		24.57	9.65		0.156

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		Supine			Standing			Between positions
		Mean	**SD**	**p Value (*)**	**Mean**	**SD**	**p Value (*)**	**p Value (*)**
Tonic contractions (in µV)	No SUI	109.79	35.78	0.462	106.19	36.45	0.971	1.000
	SUI	95.13	60.06		105.43	64.73		1.000
Baseline (in %)	No SUI	13.53	8.86	0.151	24.21	11.91	0.141	0.022
	SUI	22.80	20.54		34.72	21.60		0.011
Tonic contractions (in %)	No SUI	97.15	12.75	0.466	93.94	15.38	0.029	1.000
	SUI	100.72	11.19		118.90	35.25		0.849

Abbreviation: *MVC*, maximum voluntary contraction; *SD*, standard deviation. Significance a level was set at $p < 0.05$. Microvolt (µV) measurement unit. (*) Difference between positions according to the *p* value based on post-hoc of repeated measures ANOVA.

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Table 3**. Muscle-activation values (average amplitude) according to LH (ap).**

Average amplitude	**LH (ap) (cm)**	**N**	**Mean**	**SD**	***p* Value (*)**
MVC (in µV)	≤ 4 cm	13	124.45	40.01	**0.012**
	> 4 cm	12	81.13	39.66	
Baseline (supine) (in µV)	≤ 4 cm	13	16.29	10.37	0.177
	> 4 cm	12	11.71	4.93	
Tonic contractions (supine) (in µV)	≤ 4 cm	13	125.29	46.98	**0.012**
	> 4 cm	12	78.35	38.32	
Baseline (standing) (in µV)	≤ 4 cm	13	27.34	8.81	0.178
	> 4 cm	12	22.25	9.50	
Tonic contractions (standing) (in µV)	≤ 4 cm	13	126.51	53.65	**0.031**
	> 4 cm	12	83.43	38.06	
Baseline (supine) (in %)	≤ 4 cm	13	15.90	17.37	0.508
	> 4 cm	12	20.25	14.73	
Tonic contractions (supine) (in %)	≤ 4 cm	13	101.10	13.91	0.341
	> 4 cm	12	96.45	9.32	
Baseline (standing) (in %)	≤ 4 cm	13	24.50	14.03	0.167

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	> 4 cm	12	34.42	20.33	
Tonic contractions (standing) (in %)	≤ 4 cm	13	101.07	21.35	0.398
	> 4 cm	12	111.18	36.05	

Abbreviation: *MVC*, maximum voluntary contraction; *SD*, standard deviation. Significance a level was set at $p < 0.05$. Microvolt (μV) measurement unit.

3.3 Morphofunctional correlations of the PFMs.

Players with a smaller LH (ap) in supine have greater MVC (r = -0.549; $p = 0.005$), greater electrical activity in basal (r = -0.465; $p = 0.019$) and greater amplitude in tonic contractions. The correlations are maintained in standing ($p < 0.05$). The LPA exhibits a comparable pattern, where higher LPA levels correlate with increased basal activity in both resting (r = 0.536; $p = 0.006$) and standing (r = 0.397; $p = 0.049$) positions. The results indicate a positive correlation between the activation of the PFMs and the increase in the LPA in both supine and standing positions. Furthermore, the findings suggest a relationship between greater tonic muscle activity and higher MVC ($p < 0.05$).

Those players who increase their resting LH (ap) more when standing need to increase their basal activity more (r = -0.421; $p = 0.036$) (Figure 3). Incontinent players who produce a smaller change in LH (ap) or LPA after PFMs contraction need to work at higher basal % in supine (r = -0.743; $p = 0.006$) and standing (r = 0.887; $p < 0.001$). However, the continent players who achieve the greatest LH (ap) reduction after PFMs contraction are the ones who need the least % activation in tonics (r = -0.703; $p = 0.007$).

4. Discussion

In this sample of female rugby players, LH (ap) was larger in standing than in supine, suggesting a posture- and load-related association. A larger levator hiatus was associated with approximately 40% lower PFM electrical activity, although this finding should be interpreted with caution given the limitations inherent to sEMG

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methodology and normalization. Players with incontinence and an enlarged hiatus showed lower PFM activation values and higher activation during the same task, a pattern that may reflect greater muscular demand or a possible compensatory response. The data suggests that morphofunctional characteristics of the pelvic floor may be associated with differences in functional capacity in this athlete population.

4.1 The Structural Characteristics of the Pelvic Floor Muscles in high-impact sports.

In our study, 37% of the sample exhibited LH (ap) dimensions that overlapped with ranges previously reported in pregnant or postpartum women. When measured in standing, nearly two-thirds of participants reached those values, indicating that body position significantly impacts levator hiatus morphology. Although the increase in LH (ap) from supine to standing was statistically significant (~0.27 cm), this change represents a small absolute difference. Furthermore, LH (ap) increased significantly in incontinent players when standing, while it remained relatively stable in continent players. Its clinical relevance remains uncertain and should be interpreted with caution, particularly in the absence of established thresholds for meaningful morphological change in athletic populations.

Previous studies have used LH (ap) and LPA as primary ultrasound parameters for assessing pelvic floor structural changes [43,59,60]. DeLancey et al. [61] analyze the perineal complex to understand how the interaction between the levator ani, perineal membrane, and perineal body influences UGH closure. Although based on cadaveric perineal dissections, the anatomical insertion of the levator ani into the perineal membrane and its connection to the endopelvic fascia may help explain the morphological adaptations observed in the LH (ap). In individuals with SUI, increased basal activation might represent a compensatory response to reduced passive stabilization—potentially related to fascial or connective tissue laxity, as proposed in previous anatomical models such as DeLancey's "hammock hypothesis" [62].

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The morphological data reviewed by Cheng et al. [47] show that the LH (ap) varies based on the number of vaginal births a woman has had or the stage of pregnancy. At rest, the LH (ap) measures 4.5 (0.6) in nulliparous women, 5.0 (0.7) in women in the postpartum period between 3 and 7 months after vaginal delivery, and 4.7 (0.6), 4.6 (0.7), and 5.2 (0.7) during the first, second, and third trimesters of pregnancy, respectively. However, such morphological adaptations have not been previously documented in nulliparous female athletes.

The increase in LH (ap) observed in our sample may be consistent with repeated exposure to high IAP during high-impact sport; however, this interpretation remains speculative given the cross-sectional design. In women with SUI, increased basal activation may be a compensatory mechanism due to compromised structural support. The insertion of the levator ani into the perineal membrane and its connection to the endopelvic fascia may influence this morphological response, particularly when fascial structures are under repetitive load or fatigue. Consequently, the effect of high-impact sports on the pelvic floor morphology of such individuals is a crucial area that warrants continued study and further exploration.

4.2 The Functional Characteristics of the Pelvic Floor Muscles in high-impact sports.

Our results showed that LH (ap) increased by 7% at rest and 9% during MVC in standing compared to supine. However, LPA did not change. Baseline sEMG activity increased around 10%, and peak amplitude increased around 20% in the standing position. Players with greater LH (ap) enlargement in standing required higher basal activity to maintain support.

According to current scientific literature, the pelvic floor is more activated when standing. Unlike the supine position, where gravity is eliminated, the upright standing position may increase abdominal pressure on pelvic structures [63] and requires more intense activity of PFMs [64].

The sEMG allows measuring not only the bioelectric activity of muscle fibers but also reflex responses, coordination, and contraction speed, observing the

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functionality of the pelvic floor [65]. In our study, significant differences were found in baseline activity of the PFMs in standing versus supine position. Gimenez et al. [66] a reported a 36% increase in sEMG at rest in standing among women with SUI, and a 23% decrease in MVC compared to supine. However, we did not observe significant differences in tonic contractions between positions, suggesting that athletic training may preserve maximal contraction capacity despite increased basal demand.

The increased PFMs activation observed in standing likely reflects the need to counteract higher IAP and gravitational load. In incontinent athletes, elevated basal and tonic activity may indicate a compensatory recruitment strategy aimed at preserving continence. While this mechanism may be initially effective, it also increases the relative muscular effort required to maintain pelvic support, potentially leading to earlier fatigue during sustained tasks such as training or competition. In line with some performance-based perspectives, strength has been considered the only physical quality that can be systematically improved through training to enhance function and resilience [67,68]. From this standpoint, insufficient PFMs strength may result in an inability to meet the functional demands imposed by high-impact sports, especially when the pelvic floor is chronically overloaded.

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4.3 The Impact of Pelvic Floor Muscle Structure on Functional Outcomes.

Our within-subject analysis confirmed that the LH (ap) behaves dynamically across positions and contraction states. The hiatus significantly enlarged in standing compared to supine (mean difference ~0.27 cm at rest, $p < 0.001$), consistent with the combined effect of gravity and elevated IAP. Conversely, MVC reduced LH (ap) by ~0.5 cm ($p < 0.001$), supporting its role as an active closure and stabilization mechanism. Although these differences are statistically robust ($\eta^2 = 0.666$), their clinical relevance remains uncertain given the relatively small absolute changes. Nevertheless, the consistency of these patterns suggests that even subtle morphological shifts may alter the functional reserve of the pelvic floor, particularly under repeated high-impact loading. From a clinical perspective, these findings

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highlight that the PFMs is not a static structure but adapts dynamically to posture and muscular demand, a behavior that may be amplified in athletes exposed to sustained mechanical stresses.

Moreover, we observed that incontinent athletes had a 7.5% longer LH (ap) at rest in standing compared to supine. While this elongation was also present in continent athletes, the difference was not statistically significant. The continent group had higher, though non-significant, MVC amplitudes, while the incontinent group exhibited significantly higher relative activation during both basal and tonic contractions.

Gachon et al. [69] reported increased stiffness in LA fibers during elongation under load. Yoshida et al. [70] found that women with urinary incontinence had a significantly larger LH (ap) than continent women at 3 months postpartum. These findings support a possible relationship between pelvic floor morphology and PFMs function.

An increased LH (ap) may reflect hiatus instability and reduced support capacity, requiring greater neuromuscular activity to maintain continence. Female athletes with LH (ap) values similar to those of nulliparous women, averaging 4.0, showed 40% more voluntary activation, possibly due to better fascial support. Given that electrode–muscle distance has been proposed as a potential confounder in pelvic floor EMG, we examined whether this factor could explain the lower amplitudes observed in players with a wider hiatus. However, our data showed the opposite trend: although the levator hiatus (LH (ap)) was larger in standing (4.68 ± 0.57 cm) than in supine (4.41 ± 0.55 cm; $p < 0.001$), EMG amplitude also increased. These patterns suggest functional rather than geometric influences on muscle activation, a point that should be considered in future studies. The closure of the LH depends on muscle integrity, basal tone, contraction strength, and the condition of the connective tissues in the perineal body and perineal membrane [47].

The data obtained in the study indicate that incontinent female athletes require a 10-20% higher percentage effort to perform the same task. This aligns with the

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concept of "relative load" [71] (defined as the percentage intensity that a given stimulus represents for a given subject at a given time): incontinent athletes perform the same task at a higher percentage of their maximal capacity, leading to earlier fatigue. Resistance training literature indicates that high relative loads are harder to sustain [71–74]. Thus, these athletes may be at higher risk of PFMs fatigue during prolonged effort.

Additionally, while physical activity is not inherently harmful to the pelvic floor [24], specific strengthening exercises are required to maintain optimal function [75]. Athletes may acknowledge the importance of pelvic floor health but often lack targeted interventions.

4.4 Limitation of the study

This study has some limitations that should be considered when interpreting the findings. First, its cross-sectional design does not allow causal inference; therefore, the observed morphofunctional differences cannot be interpreted as changes induced by rugby participation, but rather as associations identified in this specific sample of athletes. Second, the final sample size was modest (n = 27), and although based on an a priori calculation, the study may still be underpowered for subgroup analyses such as continent versus incontinent players or narrower versus wider hiatus groups. These subgroup findings should therefore be interpreted as exploratory. Third, the absence of a non-athlete control group or a comparison group from other sports limits our ability to determine whether the observed characteristics are specific to rugby or reflect broader features of physically active women. Fourth, the sample included both amateur and elite players, but the study was not powered to analyze competitive level separately, which may have introduced heterogeneity in training exposure and cumulative mechanical load. Height, weight, and BMI were self-reported by participants rather than directly measured by the research team, this method may introduce reporting bias. BMI was classified according to WHO criteria; however, in athletic populations such as rugby players,

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BMI may overestimate adiposity due to greater muscle mass, and was therefore interpreted descriptively.

Our findings should be interpreted with caution since the changes in distances and angles are millimeters and occur within a small space within the lesser pelvis, so, although they may be statistically significant, the importance of these differences at a clinical level is not known completely. We decided to use vaginal sEMG in this study because perianal recordings are likely to capture responses primarily from the puborectal and anal sphincters [76]. Some players stated that the intravaginal probe, despite its light weight, caused a sensation of falling and discomfort and could preactivate the PFMs, an issue that is not reflected in our results. Previous work has also demonstrated no differences in the peak or root mean square muscle activity of sEMG signals recorded vaginally or perianally [77].

sEMG reflects PFMs activity (tone, recruitment, contraction amplitude) rather than direct force output. We did not take into account the phase of the menstrual cycle as a possible influence on the impedance of the electromyography. However, there are limitations in the use of surface electromyography, such as noise, contact artifacts or misalignment artifacts when positioning the wet electrodes [78].

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Although signals were normalized to MVC, variability due to electrode placement and tissue conductivity remains, so results should be interpreted as exploratory. Although the Periform intravaginal probe has demonstrated good reliability in static, controlled conditions (e.g., MVC recordings), potential motion artefacts may arise during more dynamic tasks. Future studies could incorporate suction-based differential electrodes, such as those developed by McLean [79,80] and colleagues, to further enhance signal stability and minimize movement-related noise in pelvic floor EMG acquisition.

Regarding the assessment position, all measurements were performed in the supine and standing position, instead of activities of daily living and sports routines in our population. Future research can extend these findings by recording responses of PFMs and IAP musculature activity to other forms of walking and running and during other dynamic tasks, such as jumping [79]. In addition, posture-specific MVC

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normalization (e.g., standing, plank, or sitting MVCs) should be explored to determine whether normalization posture affects EMG comparability across positions. These findings should be extended to larger samples and other sports modalities and with other PFD. It is necessary that science continue investigating the urogynecological factors of women in sports.

5. Conclusions

In high-impact sports like rugby, the LH (ap) is the most responsive marker to load: it enlarges in standing and narrows with MVC, reflecting its central role in pelvic floor support. In contrast, the LPA varies mainly with voluntary contraction and PFM strength (MOS), being less influenced by posture, and may thus represent a marker of contractile capacity rather than structural adaptation.

Approximately 40% lower PFMs electrical activity was observed in players with a wider LH, particularly during MVC and tonic tasks. While continent athletes displayed more efficient activation patterns, incontinent players or those with enlarged hiatus diameters exhibited c a pattern consistent with compensatory overactivation, which could contribute to greater relative effort and potentially to earlier fatigue during prolonged or high-intensity tasksSome hiatus dimensions at rest and in standing approximated those described in pregnancy or postpartum, suggesting possible adaptations of the pelvic floor to repetitive high-impact loads. However, these observations are descriptive and should not be interpreted as evidence of equivalence.

Altogether, pelvic floor health in athletes relies on the interplay between muscular activation and the structural integrity of connective and fascial supports. Both elements may be relevant for assessment and preventive strategies aimed at maintaining continence and functional resilience in high-impact sports such as rugby.

Abbreviations

BMI: body mass index

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IAP: intra-abdominal pressure

ICIQ-SF: International Consultation on Incontinence Questionnaire-Short Form

LA: levator ani

LH : levator hiatus

LH (ap): anteroposterior diameter of the levator hiatus

LPA: levator plate angle

MOS: Modified Oxford Scale

MVC: maximum voluntary contraction

PFD: pelvic floor dysfunction

PFMs: pelvic floor muscles

sEMG: surface electromyography

SUI: stress urinary incontinence

TPUS: transperineal ultrasound

UGH: urogenital hiatus

UI: urinary incontinence

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Acknowledgements

We are grateful to Dr. Angel Basas, Physiotherapist of the Royal Spanish Athletics Federation, for his ongoing efforts to enhance our understanding and support of female athletes, wherever he may be. Additionally, the authors acknowledge the contributions of Dr. Africa Lopez and Dr. Zigor Montalvo from the Medical Services of the Spanish Sports Council, who facilitated the development of this study within their facilities.

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Conceptualization, E.S.R.-L. and J.-d.-F.-G.; methodology, E.S.R.-L., J.-d.-F.-G. and M.T.-G.; formal analysis, E.S.R.-L.; investigation, C.O.-M., M.B.A.-G., M.T.-G. and J.-d.-F.-G.; resources, E.S.R.-L., M.B.A.-G. and M.B.-d.-P.; data curation, E.S.R.-L, J.-d.-F.-G., M.B.-d.-P and C.O.-M.; writing—original draft preparation, J.-d.-F.-G., E.S.R.-L. and M.T.-G.; writing—review and editing, E.S.R.-L. and C.O.-M.; visualization, E.S.R.-L.; supervision, E.S.R.-L. and C.O.-M.; project administration, E.S.R.-L. ;funding acquisition, E.S.R.-L.

All authors have read and agreed to the published version of the manuscript.

Data availability statement

The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions.

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